Designation: C 747 – 93 (Reapproved 1998)

An American National Standard

Standard Test Method for Moduli of Elasticity and Fundamental Frequencies of Carbon and Graphite Materials by Sonic Resonance[1]

This standard is issued under the fixed designation C 747; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the measurement of the fundamental transverse, longitudinal, and torsional frequencies of isotropic and anisotropic carbon and graphite materials. These measured resonant frequencies are used to calculate dynamic elastic moduli for any grain orientations.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 215 Test Method for Fundamental Transverse, Longitudinal, and Torsional Frequencies of Concrete Specimens[2]

C 559 Test Method for Bulk Density by Physical Measurement of Manufactured Carbon and Graphite Articles[3]

C 885 Test Method for Young's Modulus of Refractory Shapes by Sonic Resonance[3]

E 111 Test Method for Young's Modulus, Tangent Modulus, and Chord Modulus[4]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *elastic modulus*—the initial tangent modulus as defined in Test Method E 111.

3.1.2 *slender rod or bar*—a specimen whose ratio of length to minimum cross-sectional dimension is at least 5 but not more than 20.

3.1.3 *longitudinal vibrations*—when the oscillations in a slender rod or bar are in a plane parallel to the length dimension, the vibrations are said to be in the longitudinal mode (Fig. 1(*a*)).

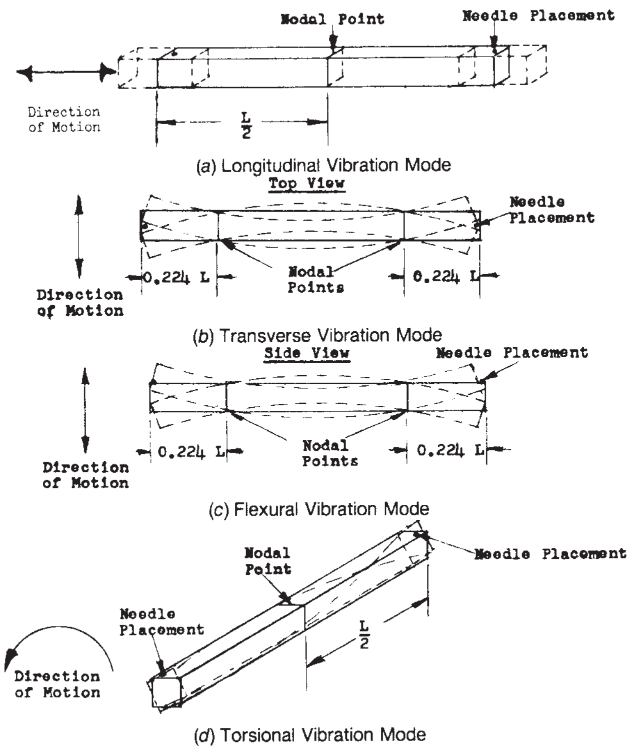

FIG. 1 Resonance Modes

3.1.4 *transverse vibrations*—when the oscillations in a slender rod or bar are in a horizontal plane normal to the length dimension, the vibrations are said to be in the transverse mode (Fig. 1(*b*)). This mode is also commonly referred to as the flexural mode when the oscillations are in a vertical plane (Fig. 1(*c*)). Either the transverse or flexural mode of specimen vibration will yield the correct fundamental frequency, subject to the geometric considerations given in 9.1.

3.1.5 *torsional vibrations*—when the oscillations in each cross-sectional plane of a slender rod or bar are such that the plane twists around the length dimension axis, the vibrations are said to be in the torsional mode (Fig. 1(*d*)).

3.1.6 *resonance*—a slender rod or bar driven into one of the above modes of vibration is said to be in resonance when the imposed frequency is such that resultant displacements for a

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[1] This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.F on Manufactured Carbon and Graphite Products.

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[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ASTM Standards*, Vol 05.05.

[4] *Annual Book of ASTM Standards*, Vol 03.01.

given amount of driving force (voltage) are at a maximum. The resonant frequency is a natural vibration frequency which is determined by the elastic moduli, density, and dimensions of the test specimen.

3.1.7 *nodal points*—a slender rod or bar in resonance contains one or more points having zero displacement, called nodal points. In the longitudinal and torsional fundamental resonances of a uniform rod or bar, the mid-length point is the nodal point (Fig. 1(*a*) and Fig. 1(*d*)). For the fundamental transverse or flexural resonance, the nodal points are located at 0.224 L from each end, where L is the length of the specimen (Fig. 1(*b*) and Fig. 1(*c*)).

4. Summary of Test Method

4.1 The dynamic methods of determining the elastic moduli are based on the measurement of the fundamental resonant frequencies of a slender rod of circular or rectangular cross section. The resonant frequencies are related to the specimen dimensions and material properties as follows:

4.1.1 *Transverse or Flexural Mode*—The equation for the fundamental resonant frequency of the transverse or flexural mode of vibration is as follows:

$$E = CMf^2 \tag{1}$$

where:

E = elastic modulus, Pa,
C = a dimensional constant that depends upon the shape and size of the specimen, and Poisson's ratio. The units of C are to be consistent with those of E, M, and f,
M = mass of the specimen, kg, and
f = frequency of fundamental transverse or flexural mode of vibration, Hz.

4.1.2 *Longitudinal Mode*—The equation for the fundamental resonant frequency of the longitudinal mode of variation is as follows:

$$E = Df^{2}L^{2}\rho \tag{2}$$

where:

E = elastic modulus, Pa,
D = a constant consistent with the units of E, f, and L,
f = frequency of fundamental longitudinal mode of vibration, Hz,
L = length of the specimen, m, and
ρ = density of the specimen as determined by Test Method C 559, kg/m^3.

4.1.3 *Torsional Mode*—The equation for the fundamental resonant frequency of the torsional mode of vibration is as follows:

$$G = R\,Bf^{2}L^{2}\rho \tag{3}$$

where:

G = modulus of rigidity, Pa,
R = ratio of the polar moment of inertia to the shape factor for torsional rigidity,
B = a constant consistent with the units of G, R, f, L, and ρ,
f = frequency of fundamental torsional mode of vibration, Hz,
L = length of the specimen, m, and
ρ = density of the specimen as determined by Test Method C 559, kg/m^3.

5. Significance and Use

5.1 This test method is primarily concerned with the room temperature determination of the dynamic moduli of elasticity and rigidity of slender rods or bars composed of homogeneously distributed carbon or graphite particles.

5.2 This test method can be adapted for other materials that are elastic in their initial stress-strain behavior, as defined in Test Method E 111.

5.3 This basic test method can be modified to determine elastic moduli behavior at temperatures from −75°C to +2500°C. Thin graphite rods may be used to project the specimen extremities into ambient temperature conditions to provide resonant frequency detection by the use of transducers as described in 6.1.

6. Apparatus

6.1 The fundamental resonant frequencies for the different modes of vibration of a test specimen can be determined by several established testing procedures. The apparatus described herein uses phonograph record pickup cartridges as a convenient method of generating and detecting these frequencies. A typical testing apparatus is shown schematically in Fig. 2.

6.1.1 *Driving Circuit*—The driving circuit consists of a variable-frequency oscillator and a record pickup cartridge assembly. It is recommended that a variable-frequency oscillator be used in conjunction with a digital-frequency counter. The oscillator shall have sufficient power output to induce detectable vibrations in the test specimen at frequencies above and below the fundamental frequency under consideration. Means for controlling the output of the oscillator shall be

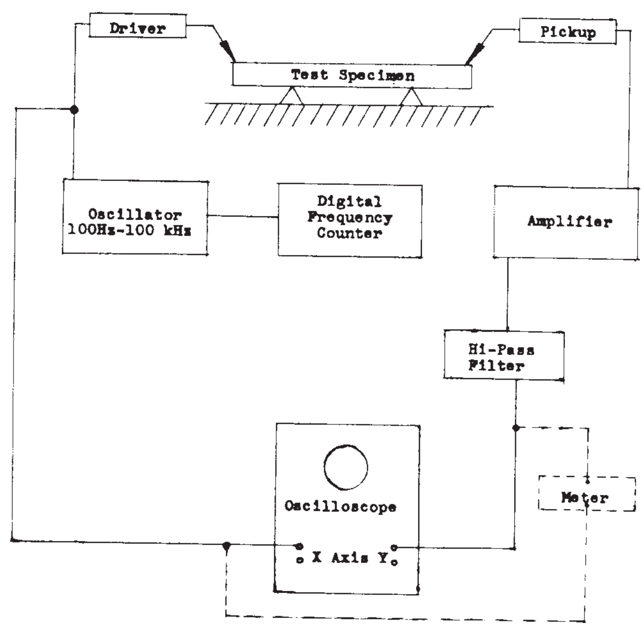


FIG. 2 Schematic Diagram of Typical Dynamic Elastic Modulus Detection Apparatus

provided. The vibrating needle of the driving unit shall be small in mass as compared to the test specimen, and a means shall be provided to maintain a minimal contact pressure on the specimen. Either a piezoelectric or magnetic driving unit meeting these requirements may be used.

6.1.2 *Pickup Circuit*—The pickup circuit consists of a record pickup cartridge, amplifier, optional high-pass filter, and an indicating meter or cathode-ray oscilloscope. The pickup unit shall generate a voltage proportional to the amplitude, velocity, or acceleration of the test specimen. Either a piezoelectric or magnetic pickup unit meeting these conditions may be used. The amplifier shall have a controllable output of sufficient magnitude to sharply peak out the resonant frequencies on the indicating meter or the cathode-ray oscilloscope display tube. It may be necessary to use a high-pass filter in order to reduce room noise and spurious vibrations. The indicating meter may be a voltmeter, microammeter or oscilloscope. An oscilloscope is recommended because it enables the operator to postively identify resonances, including higher order harmonics, by Lissajous figure analysis.

6.1.3 *Specimen Supports*—The supports shall permit the specimen to oscillate without significant restriction in the desired mode. This is accomplished for all modes by supporting the specimen at its transverse fundamental nodal points (0.224 *L* from each end). The supports should have minimal area in contact with the specimen and shall be of cork, rubber, or similar material. In order to properly identify resonant frequencies, the receiver record pickup cartridge must be movable along the total specimen length. Provisions shall be made to adjust contact pressures of both record pickup cartridges in order to accommodate specimen size variations. The entire specimen support structure shall be mounted on a massive base plate resting on vibration isolators.

7. Test Specimens

7.1 *Selection and Preparation of Specimens*—In the selection and preparation of test specimens, take special care to obtain representative specimens that are straight, uniform in cross section, and free of extraneous liquids.

7.2 *Measurement of Weight and Dimensions*—Determine the weight and the average length of the specimens within ±0.5 %. Determine average specimen cross-sectional dimension within ±1 %.

7.3 *Limitations on Dimensional Ratio*— Specimens having either very small or very large ratios of length to thickness may be difficult to excite in the fundamental modes of vibration. For this method, the ratio must be between 5 and 20 (slender rod limitations).

8. Procedure

8.1 Switch on all electrical equipment and allow to stabilize in accordance with the manufacturers' recommendations. (Use of a metal bar as a calibration standard is recommended to check equipment response and accuracy. Dimensional measurements and weight shall meet the requirements of 7.2.)

8.2 *Transverse Fundamental Resonance Frequency*:

8.2.1 Place the specimen on the supports, which are located at the fundamental transverse nodal points (0.224 *L* from each end). Place the driving and pickup-unit vibrating needles on the specimen center line at its extreme opposite ends with a minimal contact pressure consistent with good response. The vibrating direction of the driving and pickup needles must be perpendicular to the length of the specimen (Fig. 1(*b*)).

8.2.2 Force the test specimen to vibrate at various frequencies and simultaneously observe the amplified output on an indicating meter or oscilloscope. Record the frequency of vibration of the specimen that results in a maximum displacement, having a well-defined peak on the indicator, where nodal point tracking indicates fundamental transverse resonance.

8.2.3 A basic understanding of Lissajous patterns as displayed on an oscilloscope cathode ray tube (CRT), will aid in the proper identification of the modes of vibration and harmonic frequencies observed. As the oscillator frequency level is increased from a point well below expected resonance, a single closed loop Lissajous pattern tilted from the horizontal reference plane, will eventually be displayed on the CRT. This pattern denotes a resonance mode. The nodal points dynamic modulus tracking guide template (Fig. 3) may be used to identify any resonant mode.

8.2.4 Move the pickup cartridge needle slowly toward the specimen center and observe the Lissajous pattern loop. Fundamental transverse resonance is indicated when the following conditions prevail:

8.2.4.1 The loop pattern flattens to a horizontal line with the pickup needle over the specimen support.

8.2.4.2 The CRT pattern opens up to a full loop in a direction normal to its original direction, with the pickup needle over the specimen center.

8.2.5 Return the pickup needle to its original position at the specimen end.

8.2.6 Spurious resonating frequency modes may mask or attenuate the fundamental transverse frequency indication. Investigation of higher order harmonic resonating frequencies by use of the tracking guide template (Fig. 3) will help to identify the correct fundamental frequency mode. A plot of the ratio of harmonic to fundamental frequency for transverse mode of vibration (Fig. 4) may then be used to calculate the fundamental transverse resonant frequency mode.

8.3 *Longitudinal Fundamental Resonance Frequency*:

8.3.1 Leave the specimen supported at the fundamental transverse mode nodal points as in 8.2.1. Rotate the driving unit and pickup cartridge needles so as to induce vibrations parallel to the specimen length (Fig. 1(*a*)).

8.3.2 Force the test specimen to vibrate as in 8.2.2. Record the frequency of vibration of the test specimen, where nodal point tracking indicates fundamental longitudinal resonance. The second harmonic longitudinal resonant frequency is twice the fundamental longitudinal resonant frequency.

8.4 *Torsional Fundamental Resonance Frequency*:

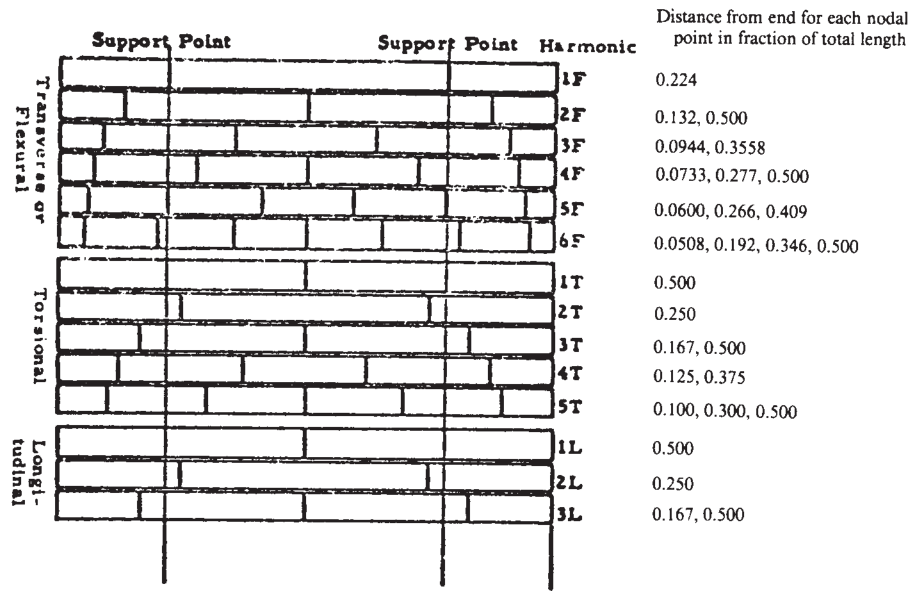
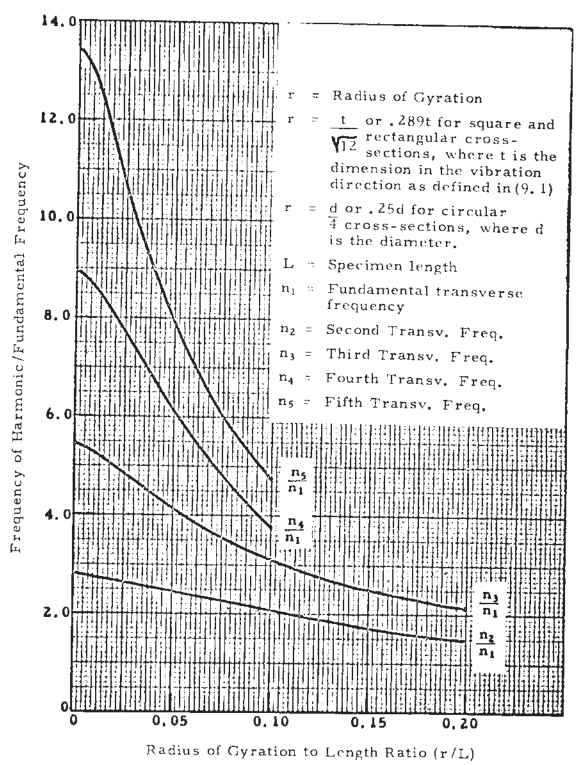


FIG. 3 Nodal Points Dynamic Modulus Tracking Guide Template



NOTE—Taken from Pickett, Gerald, "Equations for Computing Elastic Constants from Flexural and Torsional Resonant Frequencies of Vibration of Prisms and Cylinders,'' *Proceedings*, ASTM, Vol 45, 1945.

FIG. 4 Ratio of Harmonic to Fundamental Frequency for Transverse Mode of Vibration

8.4.1 Leave the specimen supported as in 8.2.1. Rotate the driving unit and pickup cartridge needles so as to induce vibrations perpendicular to the length of the sample (Fig. 1 (*d*)).

8.4.2 Force the specimen to vibrate as in 8.2.2. Record the frequency of vibration of the test specimen, where nodal point tracking indicates fundamental torsional resonance. The second harmonic torsional resonant frequency is twice the fundamental torsional resonant frequency.

9. Calculation

9.1 Calculate the dynamic modulus of elasticity for the transverse or flexural mode of vibration from the fundamental transverse frequency, weight, and dimensions of the test specimen as follows:

$$\text{Dynamic } E = CMf^{2} \quad (4)$$

where units are as defined in 3.1.1. The evaluation of the constant *C*, because of the complexity of its determination, is in tabular form. Eq 4 may be rewritten in the forms:

$$\text{Dynamic } E \text{ (pascals)} = A_c M f^{2}/d \text{ for rods with circular cross sections} \quad (5)$$

where *d* is the diameter of the rod in metres, and

$$\text{Dynamic } E \text{ (pascals)} = A_R M f^{2}/w \text{ for bars with square or rectangular cross sections} \quad (6)$$

where *w* is the width dimension of the bar in metres.

9.1.1 Values of A_c and A_R are shown in Annex A1 under Table A1.1 and Table A1.2. The value of A_c is given as a function of the diameter-to-length ratio of the sample. The value of A_R is given as a function of the ratio of the dimension in the direction of vibration, *t*, to the length. The dimension, *w*, is perpendicular to the vibration direction, as shown in Fig. 5. Table A1.1 and Table A1.2 have been calculated for three values of Poisson's ratio (μ). The value of (μ) = ⅙ is normally used for carbon-graphite materials.

9.2 The dynamic modulus of elasticity in pascals may also be calculated from the fundamental longitudinal frequency, weight, and dimensions of the test specimen as follows:

$$\text{Dynamic } E = 4.000 \; f^{2} L^{2} \rho \text{ for rods and bars} \quad (7)$$

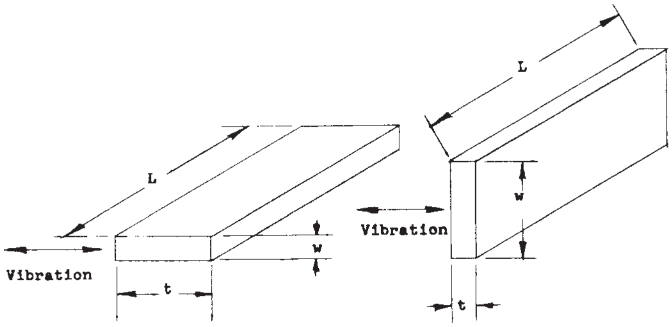


FIG. 5 Definition of Length (*L*), Width (*w*), and Thickness (*t*)

where the units are as defined in 3.1.2.

9.3 Calculate the dynamic modulus of rigidity (shear modulus) in pascals from the fundamental torsional frequency, mass, and dimensions of the test specimen as follows:

$$\text{Dynamic } G = RBf^{2}L^{2}\rho \tag{8}$$

where the units are as defined in 4.1.3.

9.3.1 The value of *R* is equal to 1 for a rod of circular cross section. *R* for bars of square cross section is 1.183. An approximate expression for *R* in the case of rectangular cross sections is as follows (see Test Methods C 215 and C 885):

$$R = \frac{[1 + (a^{2}/b^{2})]}{[4 - 2.52\,(b/a) + 0.21\,(b/a)^{5}]} \tag{9}$$

where:

a = large dimension of the rectangular cross section, and
b = small dimension of the rectangular cross section.

9.3.2 Eq 8 may be rewritten as follows:

$$\text{Dynamic G} = 4.000\ f^{2}L^{2}p \text{ for circular cylinders} \tag{10}$$

$$\text{Dynamic G} = 4.732\ f^{2}L^{2}p \text{ for square cross sections} \tag{11}$$

$$\text{Dynamic G} = 4.000\ Rf^{2}L^{2}p \text{ for rectangular cross sections} \tag{12}$$

10. Report

10.1 Report the following information:

10.1.1 Complete identification of the material being tested, including manufacturer, grade number, lot number, grain orientation, and original material size,

10.1.2 Number of specimens tested in each orientation, along with a specimen sampling plan layout,

10.1.3 Specimen dimensions and weight,

10.1.4 Average dynamic modulus for each mode group,

10.1.5 Standard deviation for each group of specimens, and

10.1.6 Environmental conditions of test including temperature, humidity, and special atmosphere (if used).

11. Precision and Bias

11.1 A precision and bias statement is being investigated and prepared.

12. Keywords

12.1 carbon; dynamic modulus; elastic modulus; graphite; modulus of rigidity; sonic resonance

ANNEX

(Mandatory Information)

A1. Table A1.1 and Table A1.2

TABLE A1.1 A_c for Rods

d/L	μ = 0	μ = 1/6	μ = 1/3	*d/L*	μ = 0	μ = 1/6	μ = 1/3
0.050	13018	13023	13035	0.108	1349	1351	1356
0.051	12273	12278	12291	0.109	1313	1316	1321
0.052	11585	11590	11603	0.110	1280	1283	1288
0.053	10945	10950	10963	0.111	1247	1247	1255
0.054	10356	10358	10371	0.112	1214	1217	1222
0.055	9807	9812	9822	0.113	1184	1186	1191
0.056	9294	9299	9309	0.114	1153	1156	1161
0.057	8819	8824	8834	0.115	1125	1128	1133
0.058	8374	8379	8390	0.116	1097	1100	1105
0.059	7960	7965	7976	0.117	1069	1072	1077
0.060	7574	7577	7590	0.118	1044	1046	1052
0.061	7211	7216	7226	0.119	1019	1021	1026
0.062	6873	6878	6886	0.120	996	998	1003
0.063	6553	6558	6568	0.121	973	975	980
0.064	6256	6259	6269	0.122	950	953	958
0.065	5977	5979	5989	0.123	927	930	935
0.066	5710	5715	5725	0.124	907	909	914
0.067	5464	5466	5476	0.125	886	889	892
0.068	5227	5232	5243	0.126	866	869	874
0.069	5006	5011	5022	0.127	846	848	853
0.070	4798	4803	4813	0.128	828	831	833
0.071	4602	4605	4615	0.129	810	810	815
0.072	4417	4420	4430	0.130	792	792	798
0.073	4239	4244	4252	0.131	775	777	782
0.074	4074	4077	4087	0.132	757	759	765
0.075	3917	3919	3929	0.133	742	744	749
0.076	3764	3769	3777	0.134	726	729	734
0.077	3625	3627	3635	0.135	711	714	716
0.078	3487	3493	3500	0.136	696	699	704
0.079	3360	3366	3371	0.137	681	683	688
0.080	3239	3241	3249	0.138	668	671	673
0.081	3122	3127	3134	0.139	655	655	660
0.082	3012	3015	3023	0.140	643	643	648
0.083	2906	2908	2918	0.141	630	630	635
0.084	2807	2809	2817	0.142	617	617	622
0.085	2710	2713	2720	0.143	605	607	610
0.086	2619	2621	2629	0.144	592	594	599
0.087	2532	2535	2540	0.145	582	582	587
0.088	2449	2451	2459	0.146	569	572	577
0.089	2367	2372	2377	0.147	561	561	564
0.090	2294	2296	2304	0.148	549	551	554
0.091	2220	2223	2230	0.149	538	541	544
0.092	2151	2154	2159	0.150	528	531	533
0.093	2083	2085	2093	0.151	518	521	523
0.094	2019	2022	2027	0.152	508	511	516
0.095	1958	1961	1966	0.153	500	500	505
0.096	1897	1902	1910	0.154	490	493	495
0.097	1842	1847	1852	0.155	483	483	488
0.098	1788	1791	1796	0.156	472	475	478
0.099	1735	1740	1745	0.157	465	467	470
0.100	1687	1689	1694	0.158	457	457	462
0.101	1638	1641	1646	0.159	450	450	455
0.102	1593	1595	1600	0.160	442	442	447
0.103	1547	1549	1557	0.161	434	434	439
0.104	1504	1506	1514	0.162	427	427	432
0.105	1463	1466	1471	0.163	419	419	424
0.106	1422	1427	1433	0.164	411	414	417

TABLE A1.1 *Continued*

d/L	μ = 0	μ = 1/6	μ = ⅓	*d/L*	μ = 0	μ = 1/6	μ = ⅓
0.107	1384	1387	1394	0.165	404	406	409
0.166	399	399	404	0.184	300	302	305
0.167	391	394	396	0.185	295	297	300
0.168	386	386	391	0.186	292	292	295
0.169	378	381	384	0.187	287	287	292
0.170	373	373	378	0.188	282	284	287
0.171	366	368	371	0.189	277	279	282
0.172	361	363	366	0.190	274	277	279
0.173	356	356	361	0.191	272	272	274
0.174	351	353	356	0.192	267	269	272
0.175	343	345	348	0.193	264	264	267
0.176	338	340	343	0.194	259	262	264
0.177	333	335	338	0.195	257	257	262
0.178	328	330	333	0.196	251	254	257
0.179	323	325	328	0.197	249	251	254
0.180	318	320	323	0.198	246	246	249
0.181	312	315	318	0.199	241	244	246
0.182	310	310	312	0.200	239	241	244
0.183	305	305	310				

TABLE A1.2 A_R for Bars

t/L	μ = 0	μ = 1/6	μ = ⅓	*t/L*	μ = 0	μ = 1/6	μ = ⅓
0.050	7701	7706	7717	0.110	767	770	775
0.051	7262	7267	7277	0.111	747	749	754
0.052	6855	6861	6871	0.112	728	732	734
0.053	6480	6485	6492	0.113	709	711	716
0.054	6129	6134	6144	0.114	693	696	699
0.055	5806	5809	5819	0.115	676	678	683
0.056	5504	5507	5517	0.116	660	660	665
0.057	5225	5227	5237	0.117	643	645	650
0.058	4961	4966	4973	0.118	627	630	635
0.059	4717	4722	4729	0.119	615	615	620
0.060	4488	4493	4501	0.120	599	602	605
0.061	4275	4277	4285	0.121	584	587	592
0.062	4074	4077	4087	0.122	572	574	577
0.063	3886	3889	3899	0.123	559	561	564
0.064	3708	3713	3721	0.124	546	549	551
0.065	3546	3548	3556	0.125	533	536	538
0.066	3388	3393	3399	0.126	523	523	528
0.067	3241	3246	3251	0.127	511	513	516
0.068	3104	3106	3114	0.128	500	500	509
0.069	2974	2979	2985	0.129	488	490	493
0.070	2850	2852	2860	0.130	478	480	483
0.071	2733	2738	2743	0.131	467	470	472
0.072	2624	2626	2634	0.132	457	460	462
0.073	2520	2522	2530	0.133	450	450	455
0.074	2421	2423	2431	0.134	439	439	445
0.075	2327	2332	2337	0.135	429	432	434
0.076	2240	2243	2248	0.136	422	424	427
0.077	2156	2159	2164	0.137	414	414	419
0.078	2075	2078	2085	0.138	406	406	409
0.079	1999	2002	2009	0.139	396	399	401
0.080	1925	1930	1935	0.140	389	391	394
0.081	1859	1862	1867	0.141	381	384	386
0.082	1793	1796	1801	0.142	373	376	378
0.083	1730	1735	1740	0.143	366	368	371
0.084	1671	1674	1679	0.144	358	361	363
0.085	1615	1618	1623	0.145	353	353	358
0.086	1560	1565	1570	0.146	345	348	351
0.087	1509	1511	1516	0.147	340	340	343
0.088	1461	1463	1468	0.148	333	335	338
0.089	1412	1415	1420	0.149	328	328	333
0.090	1367	1369	1377	0.150	320	323	325
0.091	1323	1328	1334	0.151	315	318	320
0.092	1283	1285	1290	0.152	310	310	315
0.093	1245	1247	1252	0.153	305	305	307
0.094	1202	1209	1214	0.154	300	300	302
0.095	1171	1171	1176	0.155	292	295	297
0.096	1135	1135	1143	0.156	287	290	292
0.097	1102	1102	1107	0.157	284	284	287

TABLE A1.2 *Continued*

t/L	μ = 0	μ = 1/6	μ = ⅓	*t/L*	μ = 0	μ = 1/6	μ = ⅓
0.098	1069	1072	1077	0.158	279	282	284
0.099	1041	1041	1046	0.159	274	274	279
0.100	1008	1011	1016	0.160	269	269	274
0.101	980	983	988	0.161	264	267	269
0.102	953	955	960	0.162	259	262	264
0.103	927	930	932	0.163	257	257	259
0.104	902	904	907	0.164	251	251	257
0.105	876	879	884	0.165	246	249	251
0.106	853	856	859	0.166	244	244	246
0.107	831	833	838	0.167	239	241	244
0.108	808	810	815	0.168	236	236	239
0.109	787	790	795	0.169	234	234	236
0.170	229	229	234	0.186	180	180	183
0.171	224	226	229	0.187	178	178	180
0.172	221	221	224	0.188	175	175	178
0.173	218	218	221	0.189	173	173	175
0.174	213	216	218	0.190	170	170	173
0.175	211	213	216	0.191	168	168	170
0.176	208	208	211	0.192	165	165	168
0.177	206	206	208	0.193	163	163	165
0.178	201	203	206	0.194	160	163	165
0.179	198	201	203	0.195	157	160	163
0.180	196	196	201	0.196	157	157	160
0.181	193	193	196	0.197	155	155	157
0.182	191	191	193	0.198	152	152	155
0.183	188	188	191	0.199	150	150	152
0.184	185	185	188	0.200	147	150	152
0.185	183	183	185				